REVEALING AQUIFER RESPONSES TO GLACIATIONS USING RESIDENTIAL WATER-WELL DATA

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ABSTRACT

The occurrence and rate of groundwater movement depend on aquifer parameters such as storativity and transmissivity. Tectonic movements and glacial drifts can generate enough stresses to the bedrock that can change principal stresses thus influencing those aquifer parameters. The scopes of this research were to i) study the variations in hydraulic conductivity of the sandstone aquifers due to cyclic loading and unloading of glaciers, ii) compare the hydraulic conductivity of the bedrock aquifers under glaciated and unglaciated regions, and iii) correlate the aquifer parameters with hydraulic conductivity of the aquifer. It was hypothesized that glaciated regions would have higher hydraulic conductivity than unglaciated regions and thus would correlate with higher aquifer yield. To test this hypothesis, data were collected from 14 counties in northeastern Ohio that consist of well location, well construction details, well production test, and rudimentary lithological descriptions. These results suggested that glacial loading and unloading had created new fractures and reactivated the old fractures in the bedrock aquifers more so for glaciated regions than those in unglaciated regions. Because of that, the glaciated sandstone aquifers had a higher yield than the unglaciated sandstone aquifers. Furthermore, the sandstone aquifers in the northern counties had generally higher mean hydraulic conductivity than those in the southern counties. The frequency distribution curves of hydraulic conductivity of the aquifer in the glaciated regions were significantly tighter and shifted right compared to the unglaciated regions. Aquifer thickness and total well depth displayed a stronger correlation with the hydraulic conductivity. Such findings are important to anyone interested in withdrawing a high volume of groundwater regularly. These findings suggest that the cluster of private residential wells could provide a larger and better picture of stress history of a region.

INTRODUCTION

Predicting the spatial distribution of hydraulic properties in heterogeneous sedimentary bedrock, especially when fractured, remains a challenge (Long, 1996). Tectonic forces, unloading, and weathering can influence the porosity and permeability of aquifer thereby changing aquifer parameters such as hydraulic conductivity and storativity (Lachassagne et al., 2011; Maharjan and Eckstein, 2013). Although multiple glacial events were known to exist in the region, the impact of early glaciers was yet difficult to uncover because of deeply weathered glacial deposits or overlapped by the recent glacial deposits (Hansen, 2020). Gramiger et al.'s (2017) model showed the mechanical stress generated by glacial loading and unloading produce new fractures in bedrock that is proportionate to the thickness of the ice.

METHODS

We collected data for more than 26,000 residential water wells tapped only into sandstone aquifers within 14 counties from the Division of Soil and Water Resources of the Ohio Department of Natural Resources (ODNR). The production test of residential water wells consists of static water level, pumping rate, pumping time duration, and drawdown at the end of pumping. These data were used to calculate hydraulic conductivities of sandstone aquifers at different depths using (Cooper and Jacob, 1946) approximation to (Theis, 1935) method.

$$\frac{Q}{h_o - h_{(r_w t)}} = \frac{4\pi T}{2.303\,\log\left(\frac{2.25Tt}{r_w^2 S}\right)}$$

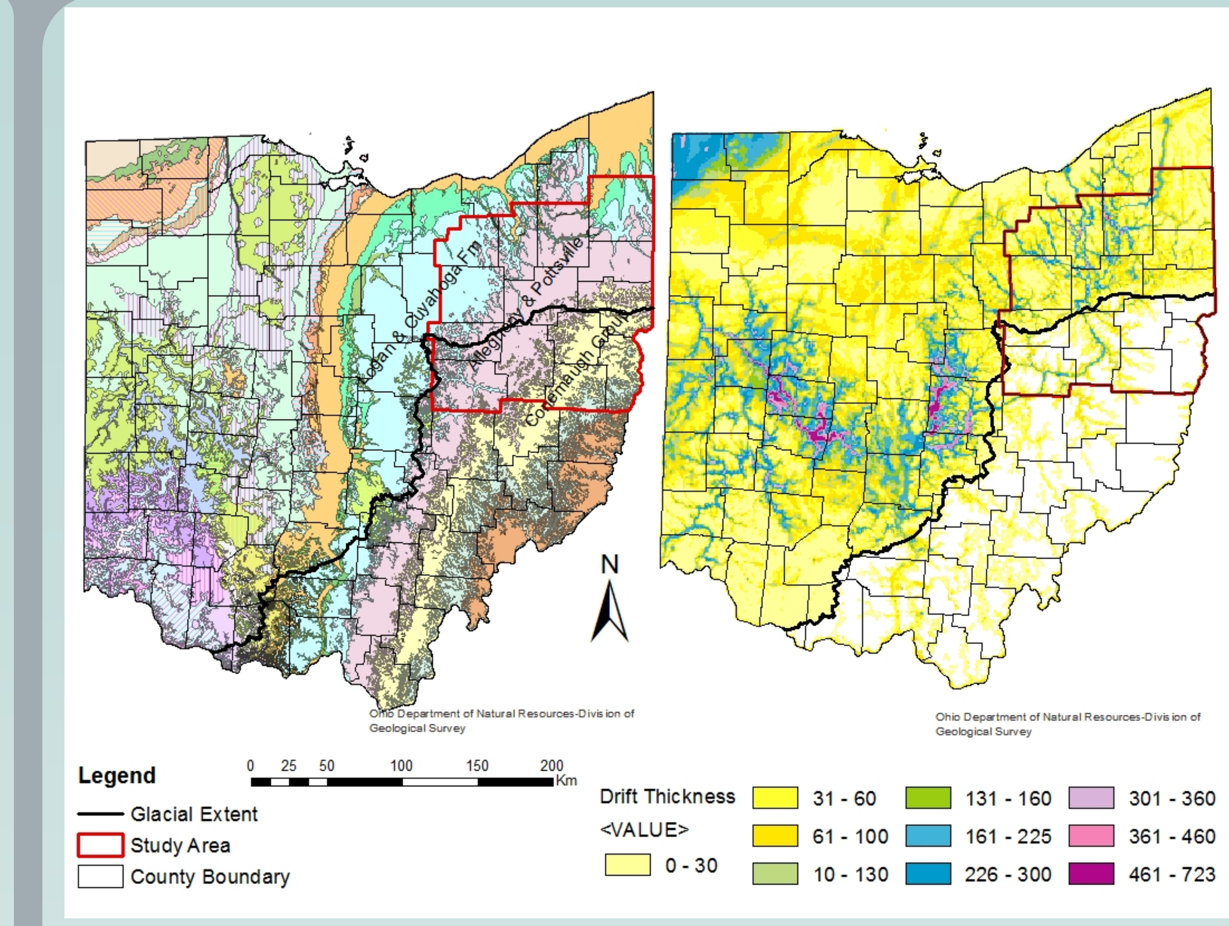

Figure 1. General geology and glacial drift thickness maps

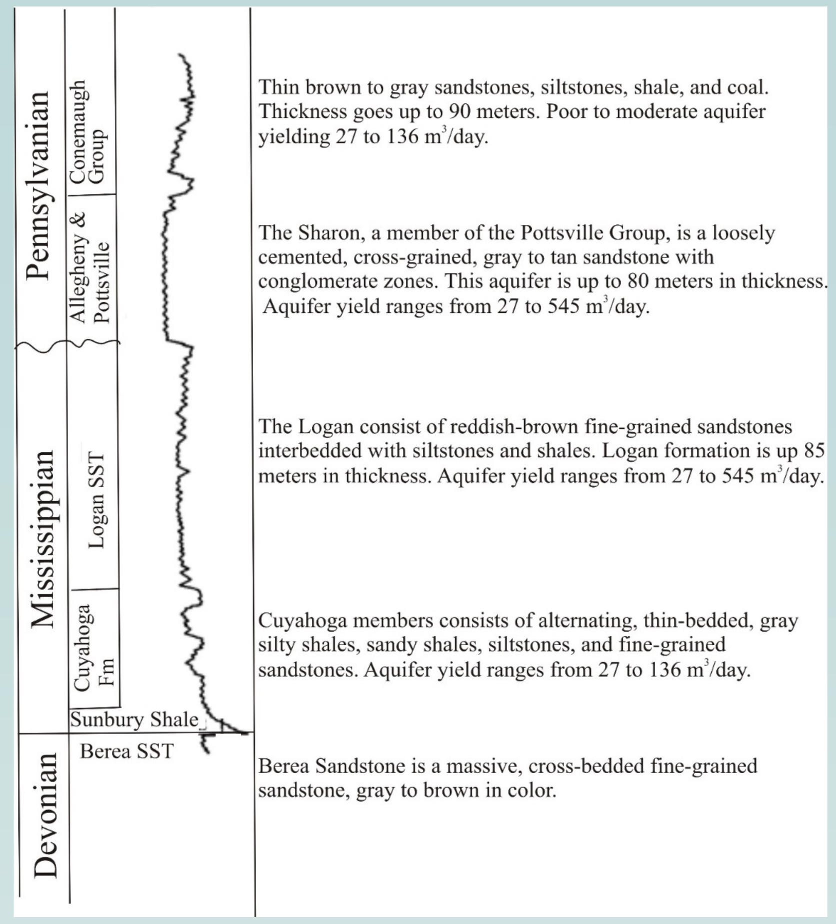

Figure 2. General stratigraphy

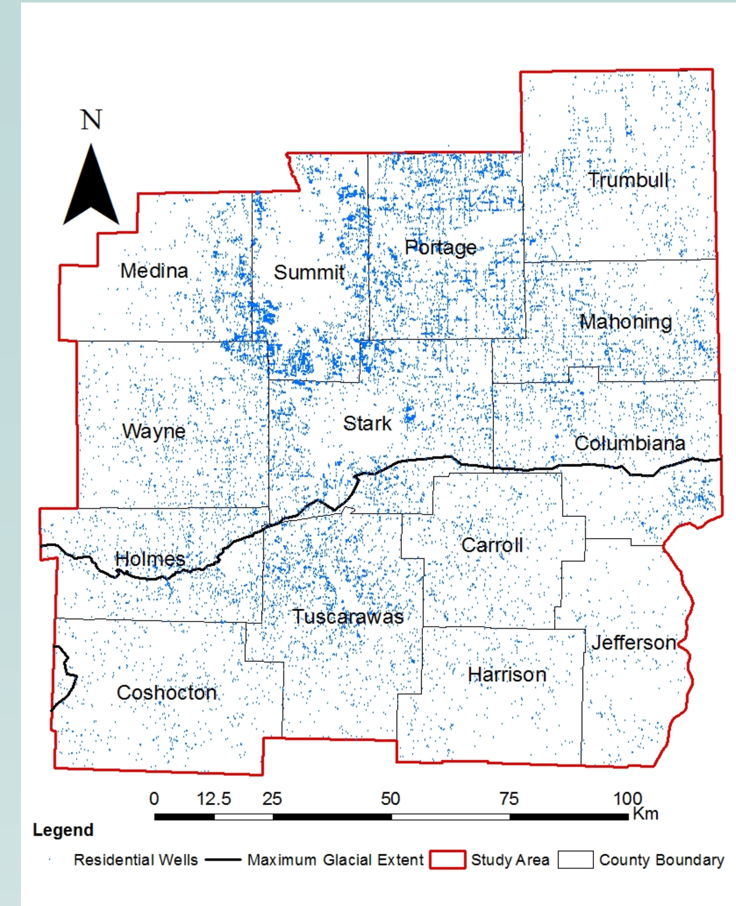

Figure 3. Well distribution

RESULTS

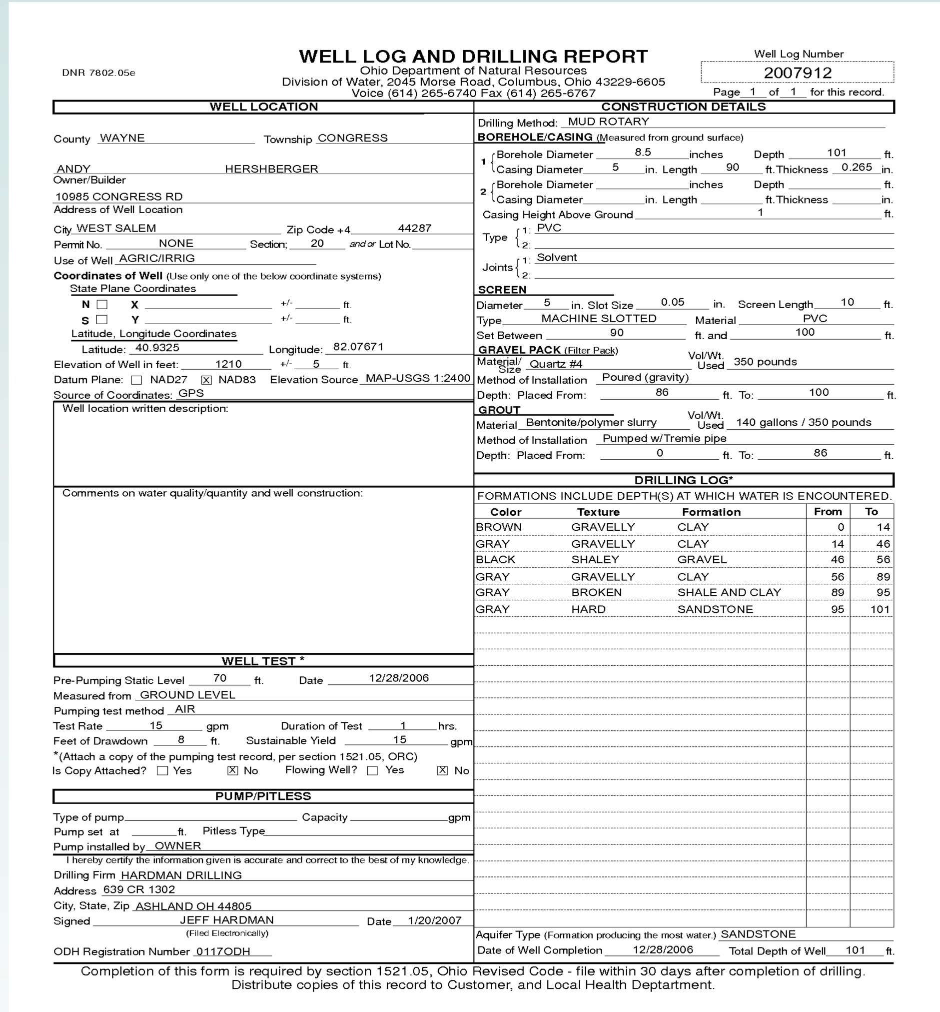

Figure 4. A sample well log and drilling report

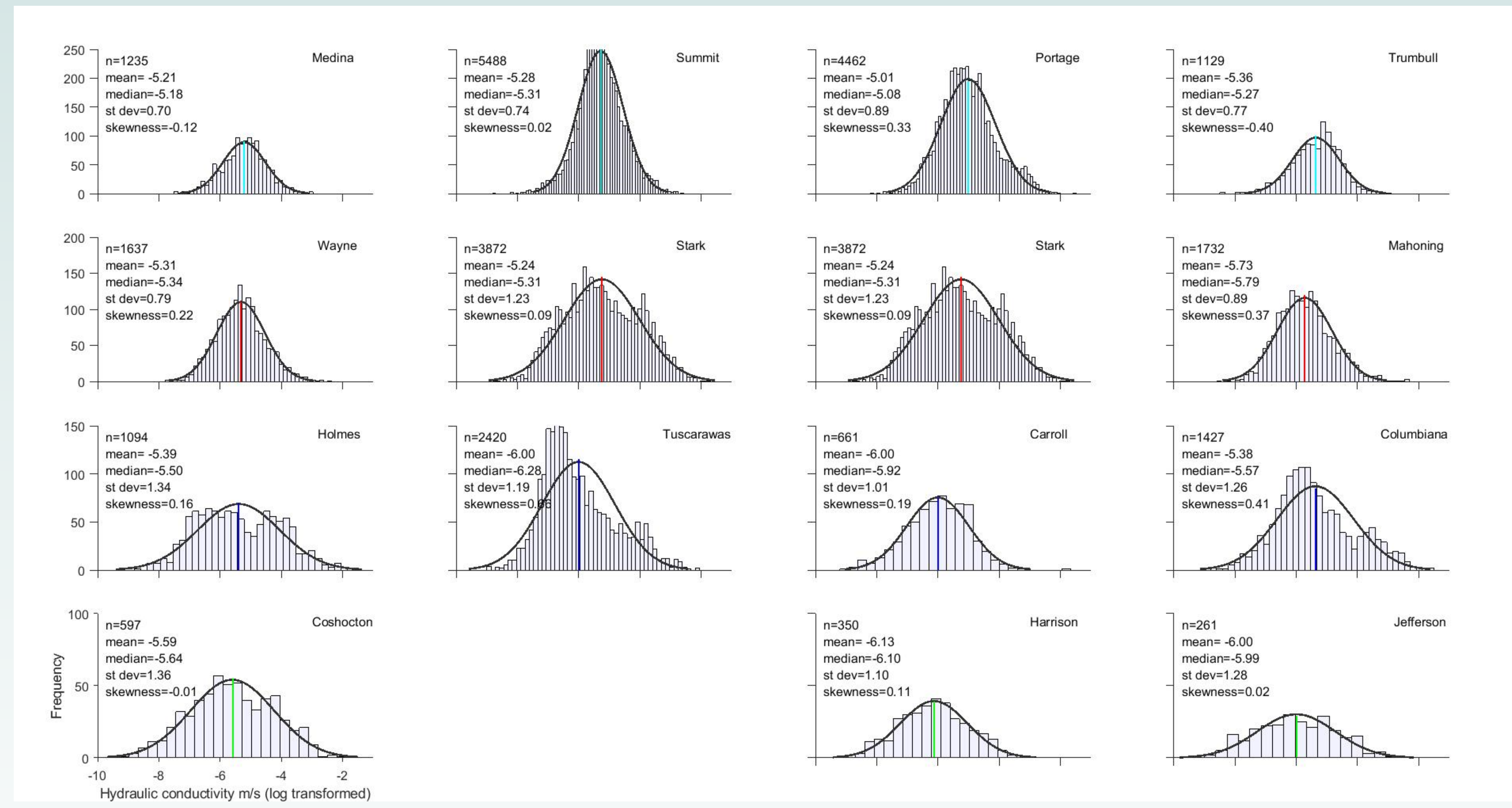

Figure 5. Frequency distribution curves for each county

County/ Regions	Numbers of wells	mean	Med	St. dev	Kurt
Glaciated*	20683	-5.24	-5.28	0.94	0.29
Mahoning	1732	-5.73	-5.79	0.89	0.30
Portage	4459	-5.01	-5.08	0.89	0.17
Summit	5488	-5.28	-5.31	0.74	0.69
Medina	1235	-5.21	-5.18	0.70	0.15
Wayne	1637	-5.31	-5.34	0.70	0.16
Trumbull	1129	-5.36	-5.27	0.77	0.45
Unglaciated*	5679	-5.90	-6.09	1.25	-0.19
Jefferson	261	-6.00	-5.99	1.28	-0.70
Harrison	350	-6.13	-6.10	1.10	-0.45
Carroll	661	-6.00	-5.92	1.01	0.25
Tuscarawas	2420	-6.00	-6.28	1.19	-0.09
Coshocton	597	-5.59	-5.64	1.36	-0.51
Columbiana	1427	-5.38	-5.57	1.26	-0.23
Holmes	1094	-5.39	-5.50	1.34	-0.75
Stark	3872	-5.24	-5.31	1.23	-0.70

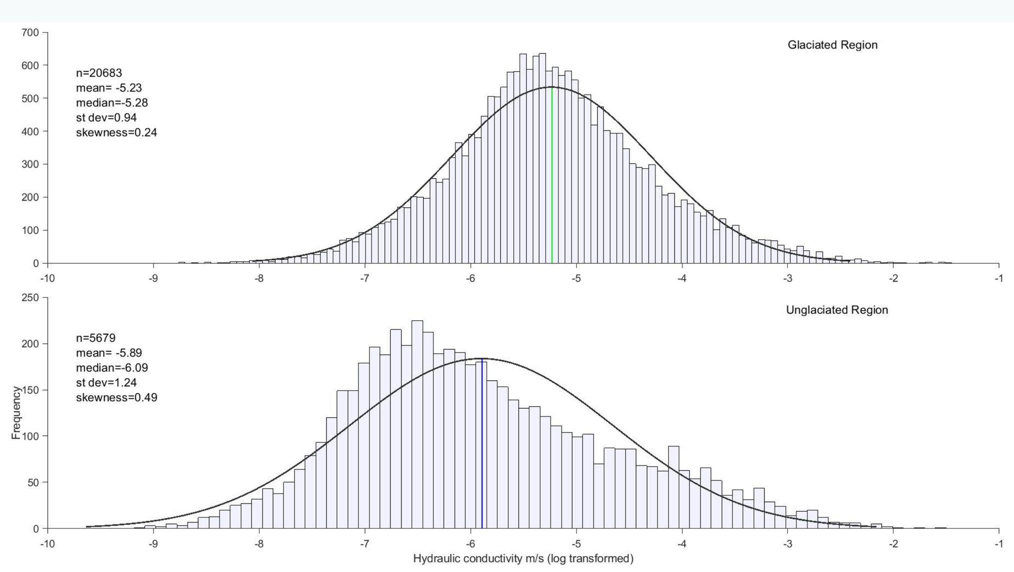

Figure 6. Frequency distribution curves for glaciated vs unglaciated regions

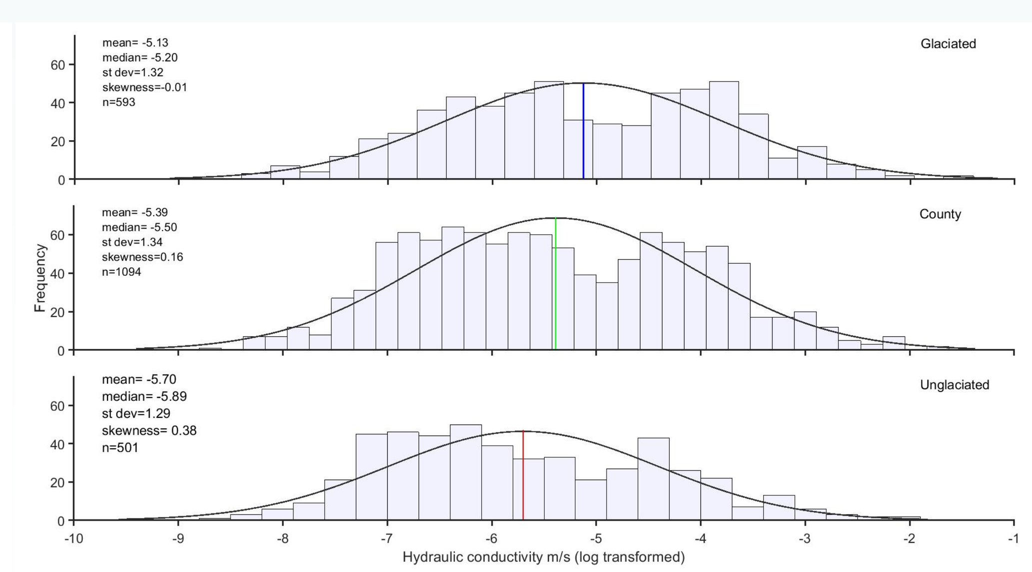

Figure 7. Frequency distribution curves for Holmes County alone

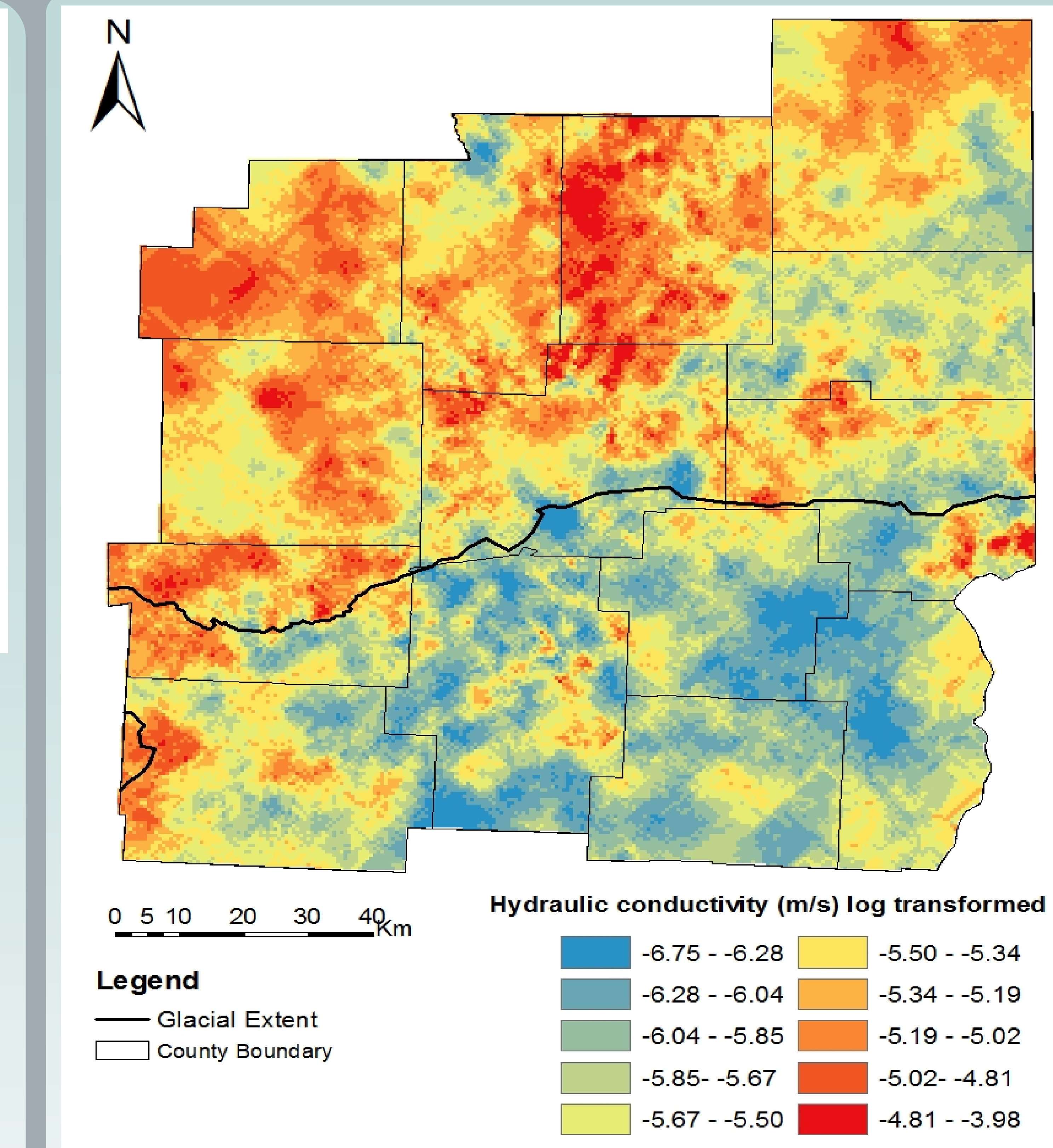

Figure 8. Spatial distribution of hydraulic conductivity

CONCLUSIONS

- Glaciated aquifers have more wells per unit area than the unglaciated aquifers
- Aquifers in the glaciated & unglaciated area responded differently to glaciations
- The mean hydraulic conductivity of glaciated area is higher than unglaciated area
- Aquifer yield is higher for glaciated regions than the unglaciated regions
- Glacial loading and unloading created new fractures and reactivated the old fractures.

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